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A MAXIMAL CHROMATIC EXPANSION METHOD
OF MAPPING MULTICHANNEL IMAGERY
INTO COLOR SPACE

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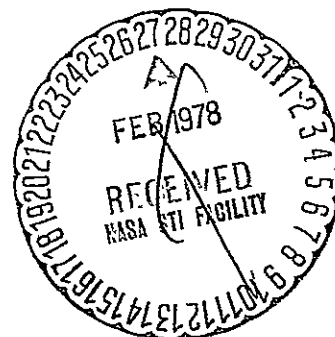
Prepared By

Lockheed Electronics Company, Inc.
Systems and Services Division
Houston, Texas

Contract NAS 9-15200

For

EARTH OBSERVATIONS DIVISION
SPACE AND LIFE SCIENCES DIRECTORATE



National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER
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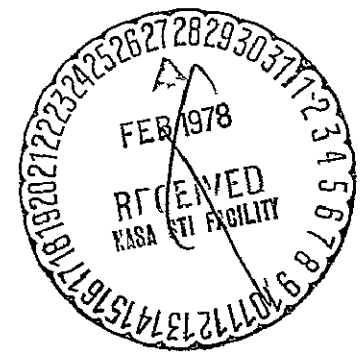
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16. Abstract A method is developed to linearly transform the Land Satellite data space into the color gun space of the film converter so that the data will occupy a maximum volume in a cube which is defined in the color gun space. Land Satellite data brightness (using the first row in the Kauth transformation) is aligned with the gray axis of the blue, green, and red gun space of the production film converter. The Kauth greenness and yellowness axes are presented orthogonally to each other and to the brightness in the color gun space.					
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1. INTRODUCTION

There have been efforts to improve the color film product that is currently being used in the Large Area Crop Inventory Experiment (LACIE). Most of those efforts (refs. 1, 2) focused on the gain and bias factors used prior to the generation of imagery. In this study, a method is developed to perform a linear transformation from the Land Satellite (Landsat) data space into the color gun space of the film converter so that the data will occupy a maximum volume in a cube defined in the color gun space. Limitations on the volume expansion are expressed in terms of placing gun saturation a specified number of standard deviations from the mean and limiting the expansion ratio so that noise-level variations in the data are not quite visible to the eye. Landsat data brightness (using the first row in the Kauth transformation, ref. 3) is aligned with the gray axis of the blue (B), green (G), and red (R) gun space of the production film converter (PFC). The Kauth greenness and yellowness are presented orthogonally to each other and to the brightness in the color gun space.

A description of the transformation involved in this new color film generation method is presented in section 2. Programming mechanics and examples are given in section 3. A subjective evaluation of this new product, along with some remarks, is presented in section 4.

2. DESCRIPTION OF THE TRANSFORMATION

Let x_b , x_g , and x_y be Kauth brightness, greenness, and yellowness, respectively. Obtain α , β , and γ as follows:

$$\left. \begin{aligned} \alpha &= \frac{(x_b - \bar{x}_b)}{\sigma_b} \frac{255\sqrt{3}}{2n} \\ \beta &= \frac{(x_g - \bar{x}_g)}{\sigma_g} \frac{255\sqrt{2}}{2n} \\ \gamma &= \frac{(x_y - \bar{x}_y)}{\sigma_y} \frac{255\sqrt{2}}{2n} \end{aligned} \right\} \quad (1)$$

where (\bar{x}_b, σ_b) , (\bar{x}_g, σ_g) , and (\bar{x}_y, σ_y) are the mean and standard deviation of the Kauth brightness, greenness, and yellowness, respectively, and n is the number of standard deviations to be used for inclusion of the data in the gun cube. Equation (1) amounts to standardizing the brightness, greenness, and yellowness, then applying a gain to the brightness so that $(\bar{x}_b \pm n\sigma_b)$ falls within $\pm \frac{255\sqrt{3}}{2}$, while applying a gain to the greenness and yellowness so that $(\bar{x}_g \pm n\sigma_g)$ and $(\bar{x}_y \pm n\sigma_y)$ falls within $\pm \frac{255\sqrt{2}}{2}$. Note that the gray axis of the PFC color gun cube is of length $255\sqrt{3}$.

Let the \underline{G} , \underline{B} , and \underline{R} color guns be three Cartesian coordinates in Euclidean space, where the bar under G , B , and R is used to indicate a vector. In equation (1), $\underline{\alpha}$ is aligned with the gray axis of the color gun cube, i.e., it points in the direction from $(0, 0, 0)$ to $(255, 255, 255)$ in the space defined above. Note that $(1/\sqrt{3}) \underline{\alpha}$ is the component along each of the \underline{G} , \underline{B} , and \underline{R} color guns. (Notice that since $\underline{\alpha}$ can take on negative values, the components of $\underline{\alpha}$ along each color gun can be negative. This will be compensated for later by adding a bias term.) Looking into the gray axis of the color gun cube as shown in figure 1, $\underline{\xi}$ is defined as lying in the $(\underline{R}, \underline{\alpha})$ plane with $\underline{\xi} \cdot \underline{\alpha} = 0$ and $\underline{\xi} \cdot \underline{R} > 0$, where " \cdot " indicates the dot product. Define $\underline{\eta}$ as:

$$\underline{\eta} = \underline{\xi} \times \underline{\alpha} \quad (2)$$

where " \times " indicates the cross product. Angle θ in figure 1 is the remaining degree of freedom with

$$\underline{\xi} = (\gamma \cos \theta - \beta \sin \theta) \underline{\xi}_i \quad (3)$$

$$\underline{\eta} = (\beta \cos \theta + \gamma \sin \theta) \underline{\eta}_i \quad (4)$$

where $\underline{\xi}_i$ and $\underline{\eta}_i$ are unit vectors along the directions of $\underline{\xi}$ and $\underline{\eta}$, respectively. Define \underline{i} , \underline{j} , and \underline{k} as unit vectors along the \underline{G} , \underline{B} , and \underline{R} vectors, respectively. Resolving $\underline{\alpha}$, $\underline{\xi}$, and $\underline{\eta}$ into components along the \underline{G} , \underline{B} , and \underline{R} directions (fig. 2) yields:

$$\underline{\alpha} = \alpha \cos \phi (\underline{i} + \underline{j} + \underline{k}) \quad (5)$$

$$\underline{\xi} = \xi \sin \phi \underline{k} + \underline{\delta} \quad (6)$$

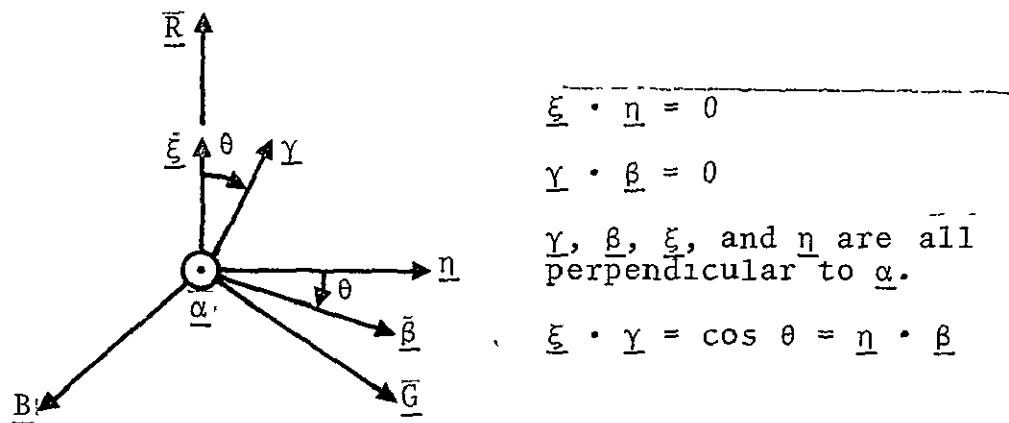


Figure 1.— Looking into the gray axis of the color gun cube.

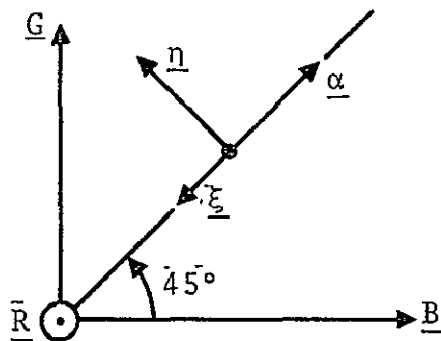
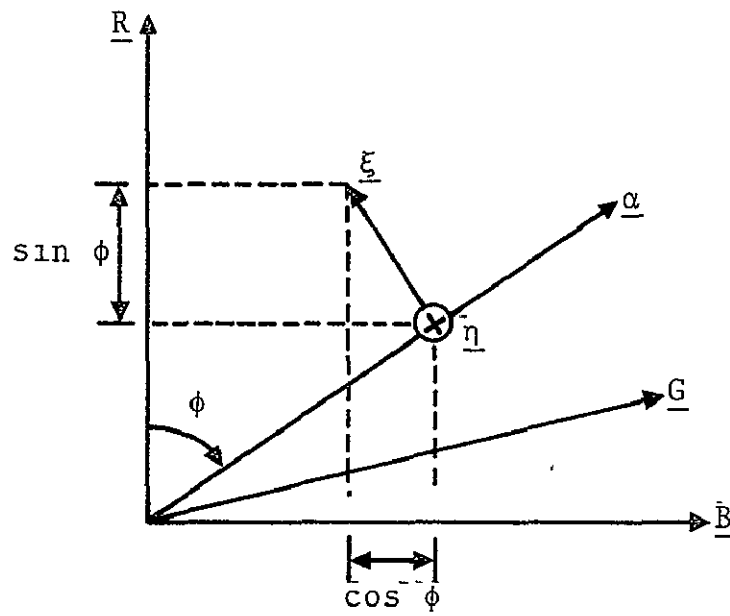


Figure 2.— Resolving $\underline{\alpha}$, $\underline{\xi}$, and $\underline{\eta}$ along \underline{G} , \underline{B} , and \underline{R} axes.

$$\underline{\delta} = -\xi \cos \phi (\underline{i} + \underline{j}) \cos 45^\circ \quad (7)$$

$$\underline{\eta} = \eta \cos 45^\circ (\underline{i} - \underline{j}) \quad (8)$$

where $\cos \phi = 1/\sqrt{3}$, and $\sin \phi = \sqrt{2/3}$. Each of the color gun axes is the sum of its components; hence,

$$R = \alpha \cos \phi + \xi \sin \phi \quad (9)$$

$$G = \alpha \cos \phi - \xi \cos \phi \cos 45^\circ + \eta \cos 45^\circ \quad (10)$$

$$B = \alpha \cos \phi - \xi \cos \phi \cos 45^\circ - \eta \cos 45^\circ \quad (11)$$

By substituting equations (3) and (4) for ξ and η in equations (10) and (11) and then adding a bias to center the color gun distributions in the cube one obtains:

$$R' = \frac{\alpha}{\sqrt{3}} - \sqrt{\frac{2}{3}} \sin \theta \beta + \sqrt{\frac{2}{3}} \cos \theta \gamma + \frac{255}{2} \quad (12)$$

$$G' = \frac{\alpha}{\sqrt{3}} + \left(\frac{\sin \theta}{\sqrt{6}} + \frac{\cos \theta}{\sqrt{2}} \right) \beta + \left(\frac{\sin \theta}{\sqrt{2}} - \frac{\cos \theta}{\sqrt{6}} \right) \gamma + \frac{255}{2} \quad (13)$$

$$B' = \frac{\alpha}{\sqrt{3}} + \left(\frac{\sin \theta}{\sqrt{6}} - \frac{\cos \theta}{\sqrt{2}} \right) \beta - \left(\frac{\cos \theta}{\sqrt{6}} + \frac{\sin \theta}{\sqrt{2}} \right) \gamma + \frac{255}{2} \quad (14)$$

3. PROGRAMMING MECHANICS AND EXAMPLES

In equations (12), (13), and (14), it is desirable to compute the R' , B' , and G' color gun values using a method that will quantize the color gun levels only once; i.e., just prior to storing those levels on a magnetic tape. In fact, once α , β , and γ are computed, it is not possible to store them on a universally formatted magnetic tape because α , β , and γ range from negative to positive values. The method used to calculate B' , G' , and R' is described as follows.

Let $\underline{C} = (B', G', R')^T$, $\underline{m}_1 = (255/2, 255/2, 255/2)^T$, $\underline{v} = (\alpha, \beta, \gamma)^T$, where T is the transpose. Define the 3 by 3 matrix M as:

$$M = \begin{bmatrix} (1/\sqrt{3}) & (\sin \theta/\sqrt{6} - \cos \theta/\sqrt{2}) & -(\cos \theta/\sqrt{6} + \sin \theta/\sqrt{2}) \\ (1/\sqrt{3}) & (\sin \theta/\sqrt{6} + \cos \theta/\sqrt{2}) & (\sin \theta/\sqrt{2} - \cos \theta/\sqrt{6}) \\ (1/\sqrt{3}) & -\sqrt{2/3} \sin \theta & \sqrt{2/3} \cos \theta \end{bmatrix}$$

$$= (m_{ij}) \quad (15)$$

Equations (14), (13), and (12), respectively, can be written as:

$$\underline{C} = M\underline{v} + \underline{m}_1 \quad (16)$$

Let \underline{X} be a four-dimensional feature vector from Landsat data with mean \underline{m} and covariance matrix Σ_X . Let K be a (3×4) matrix formed from the first three rows of the Kauth transformation matrix. Let σ_b^2 , σ_g^2 , and σ_y^2 be the first,

second, and third diagonal elements of the matrix $K\Sigma_X K^T$, respectively.

Define the matrix Λ as:

$$\Lambda = \begin{bmatrix} 255\sqrt{3}/2n\sigma_b & 0 & 0 \\ 0 & 255\sqrt{2}/2n\sigma_g & 0 \\ 0 & 0 & 255\sqrt{2}/2n\sigma_y \end{bmatrix} \quad (17)$$

The vector \underline{v} in equation (16) can be written as:

$$\underline{v} = \Lambda K \underline{X} - \Lambda K \underline{m} \quad (18)$$

Substituting equation (18) into equation (16) yields:

$$\underline{C} = A \underline{X} + \underline{b} \quad (19)$$

where

$$A = \Lambda K \quad (20)$$

$$\underline{b} = \underline{m}_1 - \Lambda K \underline{m} \quad (21)$$

Equation (19) was applied to nine LACIE segments with each segment having four acquisitions in the 1976 crop year. Some examples of the new product

as well as the current LACIE product are shown in figure 3. The new product shown in figure 3 was generated for $n = 3$ and $\theta = -\pi/2$. The value of θ was chosen to be $-\pi/2$ in order to align the greenness mostly with the red color gun of the PFC. In comparison with the current LACIE product, the new product has more contrast and colors and appears to be brighter. The field boundaries in the new product are more pronounced than in the current LACIE product.

4. REMARKS

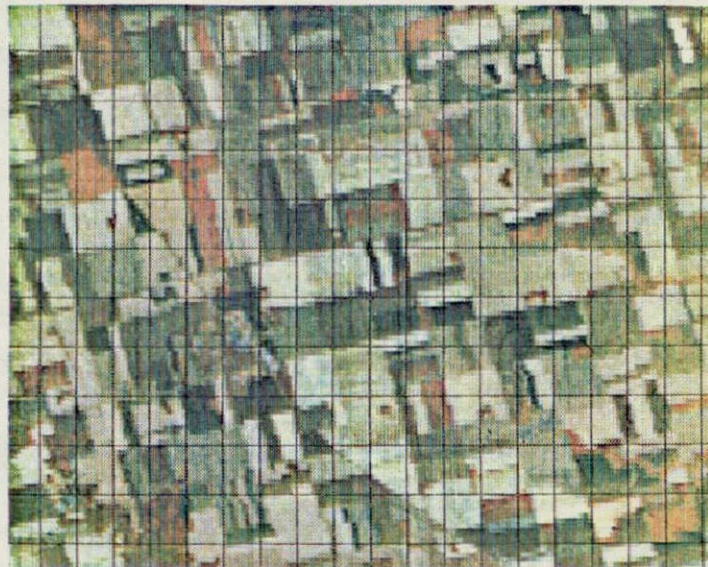
An image analyst (private communication with W. T. Hocutt of Lockheed Electronics Company, Inc., Systems and Services Division) performed a subjective evaluation of the new product and reported the following.

- a. Most acquisitions showed speckled appearance. This makes field identification difficult.
- b. The purple signature in the new product is difficult to define.
- c. In segment 1645, fields that are similar on the current LACIE product are different on the new product, and fields that are different on the current LACIE product are similar on the new product. The speckled appearance in the new product is primarily due to excessive stretching in the yellowness direction. The yellowness variance σ_y^2 of all acquisitions was examined and found to be between 1.31 and 14.66. A 14.66 yellowness variance corresponded to about a 2-percent cloud covered acquisition. An acceptable level of speckle was found to correspond to $\sigma_y^2 = 5.94$. Hence, one way of removing most of the speckle is by multiplying γ by a factor F , where

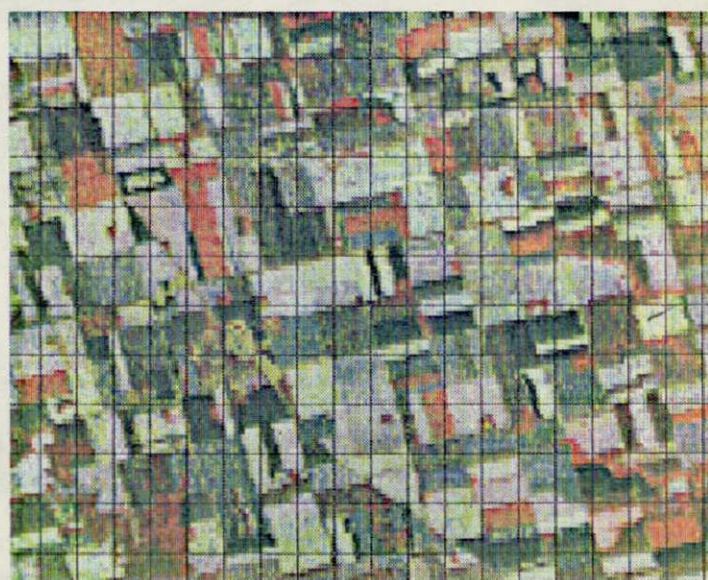
$$F = \frac{\sigma_y^2}{\text{Max}(\sigma_y^2, 6.0)} \quad (22)$$

This product produces maximal chromatic expansion of data, with certain constraints. The product is not a "true color" image, two points in data space that are linearly related do not, in general, share such chromatic attributes as hue and saturation when mapped into color space under this transformation.

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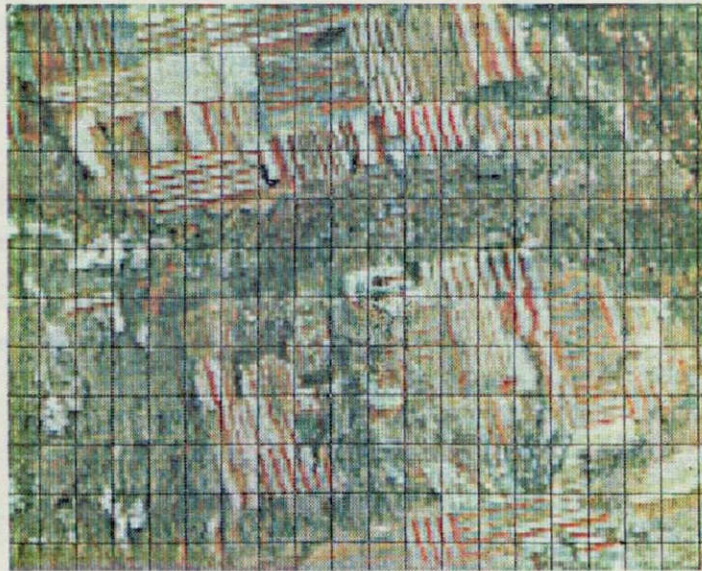
(a) Current LACIE color film product of segment 1618 in Grand Forks, North Dakota. Acquisition date: August 22, 1976.



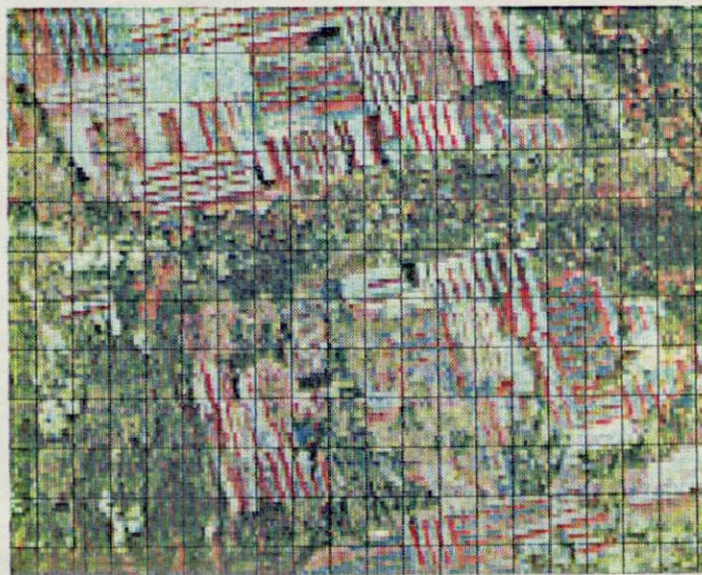
(b) New color film product of segment 1618.

Figure 3.— Some examples of the LACIE current and new color film products.

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(c) Current LACIE color film product of segment 1541.
Acquisition date: July 23, 1976.



(d) New color film product of segment 1541.

Figure 3.— Concluded.